Obtaining $|V_{ub}|$ exclusively: a theoretical perspective

Proceedings of CKM 2012, the 7th International Workshop on the CKM Unitarity Triangle, University of Cincinnati, USA, 28 September - 2 October 2012

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1 Introduction

Recent inclusive determinations of $|V_{ub}|$ have uncertainties of approximately 10% [1], as opposed to $\lesssim 2\%$ on $|V_{cb}|$ via $B \to X_c l\nu$ [2]. Exclusive channels provide a competitive alternative route to $|V_{ub}|$, but although experimentally more promising this requires information about hadronic matrix elements via form factors. Form factors are calculable via non-perturbative techniques such as Lattice QCD (see e.g. refs. [3]) or QCD sum rules on the light-cone (LCSR). Predictions are usually confined to a particular region of q^2, the momentum transfer squared, i.e. LCSR and Lattice are restricted to large and small recoil energies of the daughter hadron respectively. In LCSR one considers a correlator Π_μ of the time-ordered product of two quark currents, sandwiched between the final state hadron, which is on shell, and the vacuum [4], i.e. for a B decaying to a π of momenta p_B and p,

$$\Pi_\mu = i\, m_b \int d^D x e^{-i\, p_B\cdot x} \langle \pi(p)| T\{\overline{u}(0)\gamma_\mu b(0)\overline{b}(x) i\gamma_5 d(x)\}|0\rangle. \tag{1}$$

This can be expressed on one hand by a light-cone expansion via perturbative hard scattering kernels convoluted with non-perturbative light-cone distribution amplitudes (LCDAs), ordered in increasing twist, or by inserting a sum over excited states, i.e. the b hadron and a continuum of heavier states. Assuming quark hadron duality above a certain continuum threshold s_0, one can subtract this continuum contribution from both sides. Borel transforming this relation then ensures that this assumption, and the truncation of the series, have a minimal effect on the resulting sum rule. At present, $|V_{ub,excl}|$ is obtained most precisely from $B \to \pi l\nu$, where in the limit of massless leptons the decay rate for $B \to \pi$ depends on a single form factor $f_+(q^2)$. However by considering other channels, e.g. baryonic decays such as $\Lambda_b \to pl\nu$, one can obtain interesting complementary information.[1] Here I will discuss recent progress in the calculation of the form factors for $B \to \pi l\nu$ [9] and $\Lambda_b \to pl\nu$ [8] using LCSR.

[1] In the limit of massless leptons the decay rate for $\Lambda_b \to pl\nu$ depends on four form factors, $f_{1,2}(q^2)$ and $g_{1,2}(q^2)$.

2 Recent LCSR updates on $f_+(q^2)$ for $B \to \pi l\nu$

There has been much progress in the LCSR calculations of $f_+(q^2)$ in the last 15 years. The next-to-leading order (NLO) corrections to $f_+(q^2)$ at leading twist (twist-2) were first calculated in LCSR in ref. [5] and LO corrections up to twist-4 were calculated in ref. [6]. Since the LO twist-3 contribution was found to be large, it was confirmed that the NLO corrections are under control, using both the pole and $\overline{\mathrm{MS}}$ mass for m_b [7]. In ref. [8], different values for the moments of the twist-2 LCDA were employed, extracted from latest experimental data for F_π using LCSR. The normalised decay rate integrated over a given range in q^2,

$$\Delta\zeta(0, q^2_{\mathrm{max}}) = \frac{1}{|V_{ub}|^2} \int_0^{q^2_{\mathrm{max}}} dq^2 \frac{d\Gamma}{dq^2}(\Lambda_b \to pl\nu), \tag{2}$$

was then predicted to be $\Delta\zeta(0, 12\mathrm{GeV}^2) = 4.59^{+1.00}_{-0.85}\,\mathrm{ps}^{-1}$, which can be combined with experimental predictions, allowing the extraction of $|V_{ub}|$.

Two-loop corrections to the form factor $f_+(q^2)$ at twist-2 were recently calculated in ref. [9]. In light of the large two-loop sum rules corrections to f_B calculated in ref. [10], one aim of this work was to test the argument that, in obtaining $f_+(q^2)$ via LCSR, radiative corrections to $f_+ f_B$ and f_B should cancel when both calculated in sum rules. Due to the technical challenges posed by a full calculation, a subset of two-loop radiative corrections for twist-2 contribution to $f_+(0)$ proportional to β_0 was considered, as this gauge invariant subset is thought to be a good approximation to the complete next-to-next-to-leading order (NNLO) result. In combination with the experimental result for $f_+(0)|V_{ub}|$ one can then obtain $|V_{ub}|$. The necessary diagrams are obtained by inserting a fermion bubble in the gluon propagator of the NLO twist-2 diagrams, further details can be found in ref. [9]. The results for $f_+(0)$, seen in fig. 1, show that despite the $\sim 9\%$ positive NNLO corrections to the QCD sum rules result for f_B, the LCSR prediction for $f_+(0)$ is stable, increasing by $\sim 2\%$ to $f_+(0) = 0.261^{+0.020}_{-0.023}$, as shown in fig. 1. This enforces the stability of LCSR with respect to higher order corrections, and could be taken to provide confirmation that f_B from sum rules, not Lattice should be used here. A recent analysis by BaBar [11] finds $|V_{ub}| = (3.34 \pm 0.10 \pm 0.05 +^{+0.29}_{-0.26})10^{-3}$ using this result, and $|V_{ub}| = (3.46 \pm 0.06 \pm 0.08^{+0.37}_{-0.32})10^{-3}$ using $\Delta\zeta(0, 12\,\mathrm{GeV}^2)$ from ref. [8], which are clearly in good agreement.

3 Improvements on form factors for $\Lambda_b \to p$ decays

Recently there has been increasing work on extracting $|V_{ub}|$ via $\Lambda_b \to pl\nu$. A number of complications arise in LCSR when baryons are considered instead of mesons, the first being the choice of the heavy-light baryon interpolating current η described by

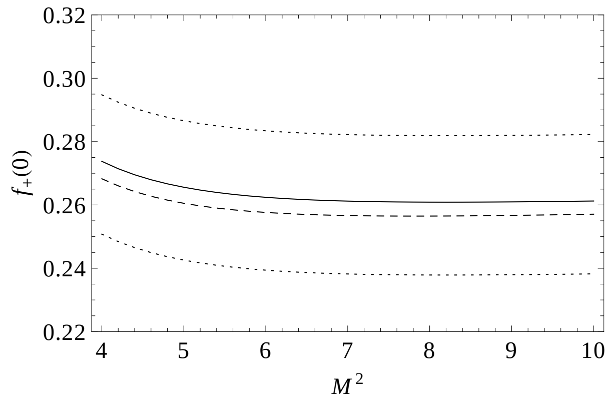

Figure 1: $f_+(0)$ at $\mathcal{O}(\alpha_s^2\beta_0)$ for central values of input parameters (solid) with uncertainties (dotted), compared to the $\mathcal{O}(\alpha_s)$ result calculated using $s_0 = 34.3\text{GeV}^2$ (dashed), as a function of the Borel parameter M^2.

Γ_b and $\tilde{\Gamma}_b$,

$$\eta = \epsilon^{ijk}(u_i C \Gamma_b d_j)\tilde{\Gamma}_b c_k, \tag{3}$$

debated since the 1980s. Additionally, the contribution of the negative parity Λ_b^* baryon, with $J^P = 1/2^-$, which has a similar mass to Λ_b is difficult to isolate, and in the literature was often included in the continuum [12]. Recently however it was found to be possible to separate the Λ_b^* from the Λ_b contribution in the sum rule, and on comparing results for both $\Gamma_b = \gamma_5(\gamma_5\gamma_\lambda)$ and $\tilde{\Gamma}_b = 1(\gamma_\lambda)$, it was found that the resulting form factors show a reduced dependence on the choice of Γ_b and $\tilde{\Gamma}_b$ [13].

4 Summary and Outlook

Recent progress on the LCSR calculation of form factors for the exclusive determination of $|V_{ub}|$ was presented. This included recent updates on $f_+(q^2)$: the 2011 NLO analysis in the $\overline{\text{MS}}$ scheme resulted in $|V_{ub}| = (3.46 \pm 0.06 \pm 0.08^{+0.37}_{-0.32})10^{-3}$ and the 2012 $\mathcal{O}(\alpha_s^2\beta_0)$ result found a $\sim 2\%$ increase in $f_+(0) = 0.262^{+0.020}_{-0.023}$, such that $|V_{ub}| = (3.34 \pm 0.10 \pm 0.05 +^{0.29}_{-0.26})10^{-3}$. New results for the form factors for $\Lambda_b \to pl\nu$ were also discussed, where it was showed that by isolating and removing the negative parity baryons' contribution, the form factors show a reduced dependence on the choice of Γ_b and $\tilde{\Gamma}_b$. Future work should focus on combining the $\mathcal{O}(\alpha_s^2\beta_0)$ $f_+(0)$ and Lattice results to determine $|V_{ub}|$ and calculating remaining twist-2 NNLO corrections to $f_+(q^2)$ and gluon radiative corrections to the $\Lambda_b \to p$ form factors.

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